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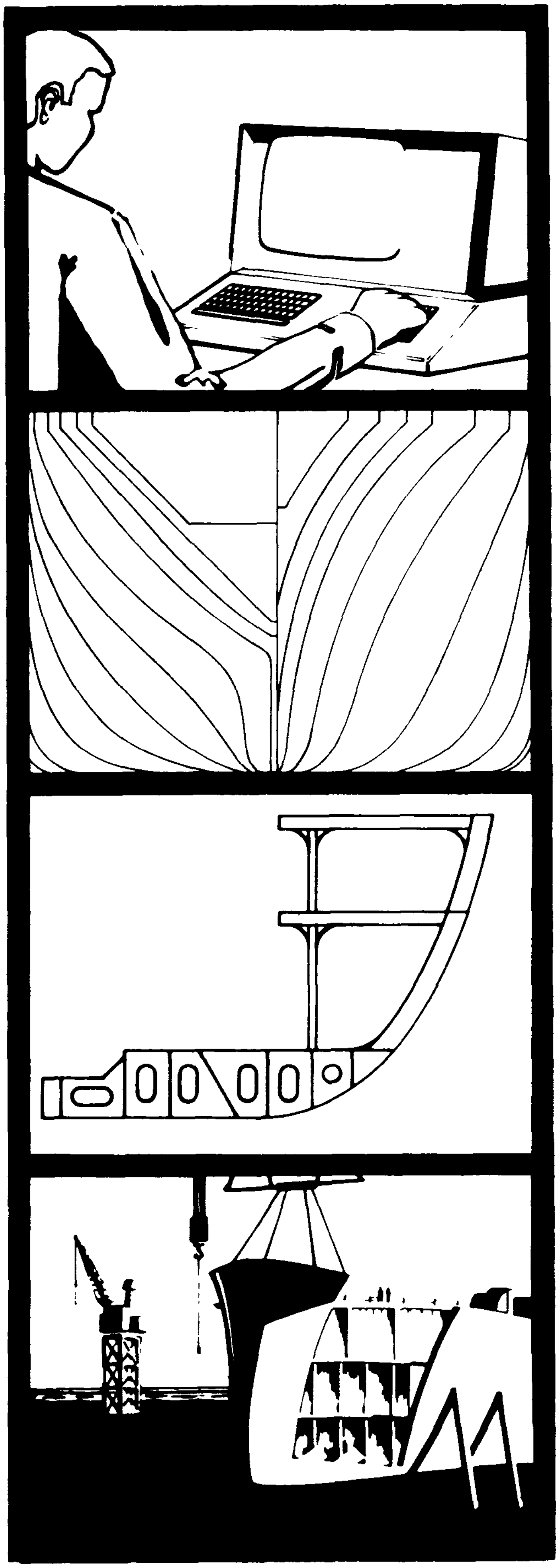

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GENERATING NEW SHIP LINES FROM A PARENT HULL
USING SECTION AREA CURVE VARIATION

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1. ABSTRACT

Section area curve variation may be used to obtain a new set of fair ship lines from a parent hull by varying any or all of the following parameters: prismatic coefficient, longitudinal center of buoyancy, extent of parallel midbody, or slopes at entrance and run. A standard series may be obtained by varying any one of these parameters independently while holding the other parameters constant. Deriving a new set of ship lines using this approach has an advantage over other methods since a known parent hull with good stability, resistance, seakeeping, etc, qualities may be selected as the starting point for the new design.

In this paper a linear system of 10 simultaneous equations is presented which allows the independent variation of three of the parameters: prismatic coefficient, longitudinal center of buoyancy, and extent of parallel midbody on a parent section area curve. Another linear system of 12 simultaneous equations is presented which allows the independent variation of the above three parameters and the slopes at the entrance and run of a parent section area surve. A new set of ship lines can be obtained directly from the new section area curve. Matrix methods are used to solve the systems of equations. Several examples with numeric and graphic results from a computer program developed at the Maritime Administration are presented.

2. INTRODUCTION

There are several methods used today for creation of ship lines by computer. For example, ship lines can be derived from one of the following:

a) a single parent hull (lines distortion approach)
b) a series of parent hulls (standard series approach)
c) geometrical hull form parameters (form parameter approach)

In the lines distortion approach new lines are obtained from the lines of one parent hull by modifying some form parameters, e.g. prismatic coefficient, longitudinal center of buoyancy, parallel midbody, etc. The advantage here is that known parent hull with good stability, resistance, and seakeeping qualities may be selected as the starting point for the new design. Lackenby [1]* developed a systematic mathematical approach to lines distortion of section area curves. Soding [2] developed transformation functions to distort section area curves, bilge radii, u-or-v shapes, stem and stern contours, etc.

Using the standard series approach, the derived hull form can be obtained by simply interpolating within the designs of that series. It is interesting to note that a standard series can be derived from a single parent or several parent designs by systematic variation methods such as lines distortion. (For example, the hulls of the British BSRA series were generated from several parent hulls using the lines distortion approach.developed in [1].) The parent designs and the deduced variations are model tested and then documented with the published standard series in terms of offsets, lines, curves of form, and resistance and propulsive data. Some of the standard series are: Japanese, British, and Swedish tanker and cargo series, German HSVA series, Taylor series, Series 60.

* Numbers in brackets designate References at end of paper.

In contrast to the lines distortion approach and the standard series approach, the form parameter approach does not require parent hulls. The new lines are created mathematically according to specified values of the parameters that define the significant curves of the new hull form. Of the three approaches, the form parameter approach allows the greatest range of form variation and consequently requires a very experienced designer. Further discussion of use of form parameters can be found in the paper by Nowacki [3J.

Depending on which approach is used to generate the derived hull form, the resistance will be known to varying degrees. In the standard series approach, resistance information can be interpolated from the tabulated series resistance data, so the resistance of the derived hull is known. In the lines distortion approach, the resistance of the parent is known, so that of the derived hull can be expected to be very similar since only moderate modifications to the parent are allowed with this method. (It should be noted that while the resistance will be similar, there is no guarantee that the new hull will produce <u>better</u> hydrodynamic behavior than the parent.) In the form parameter approach the resistance is not known.

The following presentation is concerned only with the lines distortion approach. In particular, the section area curve variation method developed in reference [l] is modified and extended. The objective is to systematically distort the section area curve of the parent hull using a mathematical approach such that the new section area curve - and therefore the new hull form - will have the desired characteristics.

3. THE LINES DISTORTION APPROACH- SECTION AREA CURVE VARIATION

Several authors have addressed section area curve variation, but one of the most complete papers was presented in 1950 by Lackenby [l]. He derived the equations for the independent variation of three parameters of the section area curve: prismatic coefficient (C_P), longitudinal center of buoyance (LCB), and extent of parallel midbody. Any or all of the three parameters could be varied independently holding the other parameters constant. For example, LCB could be varied holding CP and extent of parallel midbody constant. This represented a significant improvement over such traditional methods as "swinging" the section area curve to shift the LCB. With the traditional methods, there is no control over the position of parallel midbody or position of maximum section; they are shifted forward or aft with the new LCB. Additionally, the prismatic coefficient is changed slightly.

To develop the equations for section area curve variation, a figure with some definitions will prove useful. If areas of transverse sections at stations along the length of the ship are calculated up to the design waterline and then plotted, the resulting curve is called the section area curve. See Figure 1. It has the following properties:

a) The area under the curve is-equal to the underwater volume, ^{v}, of the ship at the.design waterline, DWL.
b) The first moment of the area is equal to the longitudinal center of buoyancy, LCB.
c) The non-dimensionalīred area under the curve is the prismatic. coefficient. Alternately, the maximum section area, A_M, when multiplied by the ship length, ^{L}SAC, gives a prison volume; this volume divided into the actual ship volume, y , is the prismatic coefficient, Cp.

Ship Profile

T	=	draft
DWL	=	design waterline
$\otimes$	=	midships
FP	=	forward perpendicular
AP	=	aft perpendicular

Section Area Curve

$A_S(x)$	=	curve of section area below DWL vs length
A_M	=	maximum section area or area of midship section
L_F	=	length of forebody
L_A	=	length of aftbody
L_{SAC}	=	length of section area curve
	=	$L_F + L_A$
X_{LCB}	=	longitudinal center of buoyance
X_F	=	abscissa of centroid of forebody
X_A	=	abscissa of centroid of aftbody
∇_F	=	underwater volume of forebody
∇_A	=	underwater volume of aftbody
∇	=	total underwater volume
	=	$\nabla_F + \nabla_A$
θ_{PF}	=	angle of entrance
θ_{PA}	=	angle of run

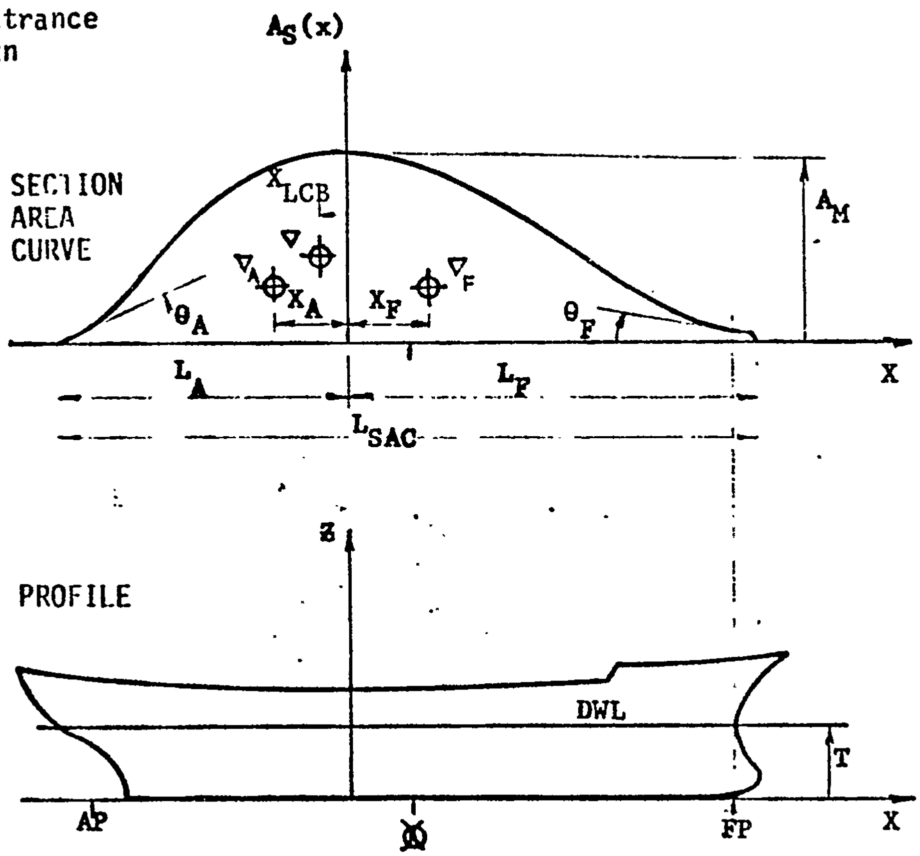

FIGURE 1. Section Area Curve Without Parallel Midbody

Note that the equations for section area curve variation apply equally well to waterlines. Only the terminology changes:

	Section Area Curve	Waterlines
Areas ;	underwater volume, V	waterplane area
Moments :	longitudinal center of buoyancy, LCB	longitudinal center of flotation, LCF
Non-dimensional areas:	prismatic coefficient, C_p	waterplane coefficient

The system of equations developed in [1] have three important limitations. The first being that length of forebody must be the same as length of aftbody. This is a result of the assumptions that the boundary between forebody and aftbody is exactly midships and that the stations forward of the forward perpendicular could be neglected. See Figure 2.

These assumptions cannot be made with the bulbous bows of today where the bulb volume is a non-negligible quantity, and with high speed cargo ships which have no parallel midbody and the station of maximum area is aft of midships. So the equations are rederived for a dimensional section area curve where length of forebody and aftbody may differ (as in Figure 1.).

The second limitation is that the original system of equations was solved by successive substitution. This obscures the presentation and makes the addition of new boundary conditions extremely difficult. A more general approach is to formulate the equations in matrices and use a direct numerical method like Gaussian elimination for the solution. A matrix approach greatly facilitates including additional boundary conditions in the system of equations, as will be done in what follows.

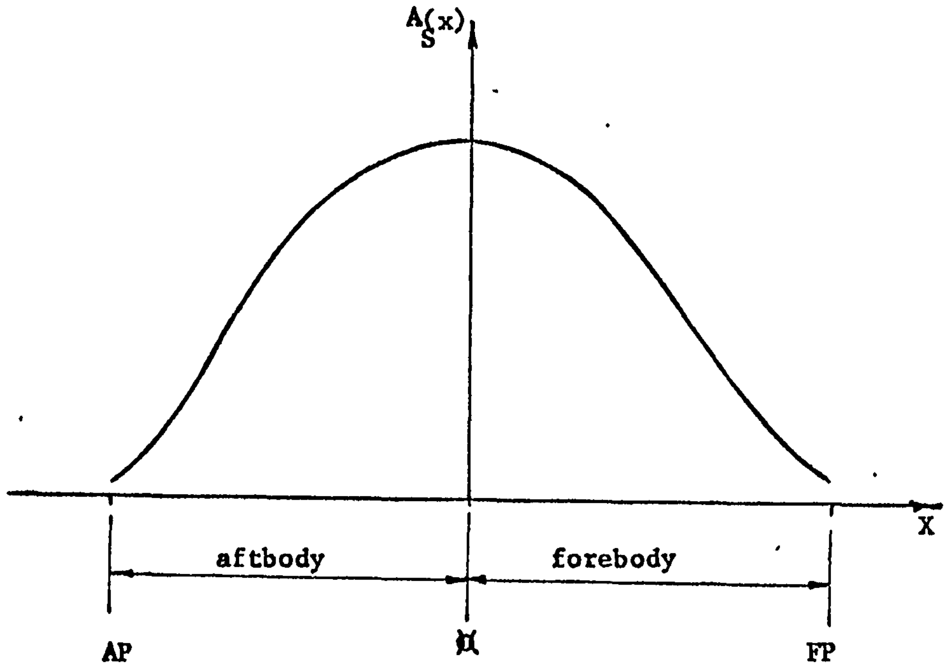

FIGURE 2. Sectio- Area Curve with Equal Forebody and Aftbody Lengths

A third limitation is that the equation for the longitudinal shifts of stations on the parent section area curve is not in general form. The equation for longitudinal shifts of stations determines how the original stations on the parent section area curveare shifted longitudinally to produce the derived section area curve with the desired characteristics. When the equation for longitudinal shifts has been calculated, the original offset stations are also shifted according to that equation to produce the new offset stations; the heights and half-breadths remain constant and only the stations are changed. The 8x value a point on the parent section area curve is shifted longitudinally is plotted vertically in the curve of longitudinal shifts in Figure 3.

In this paper the curves of longitudinal shifts of stations are second or third order equations.1 There is one equation for the longitudinal shifts in the forebody and another equation for longitudinal shifts in the aftbody. Note in the example in Figure 3 that forebody stations on the parent section area curve are shifts forward (positive shifts) while aftbody stations on the parent section area curve are shifted forward (negative shifts).

As mentioned previously, the equation for longitudinal shifts of stations determines how the original stations on the parent section area curve are shifted longitudinally to produce a derived section area curve with the desired characteristics. So the objective is to calculate the coefficients of the equation for longitudinal shifts in the forebody and aftbody, We shall now present two systems of equations whose solutions are the coefficients of the equations of the longitudinal shifts. The first system of 10 linear simultaneous

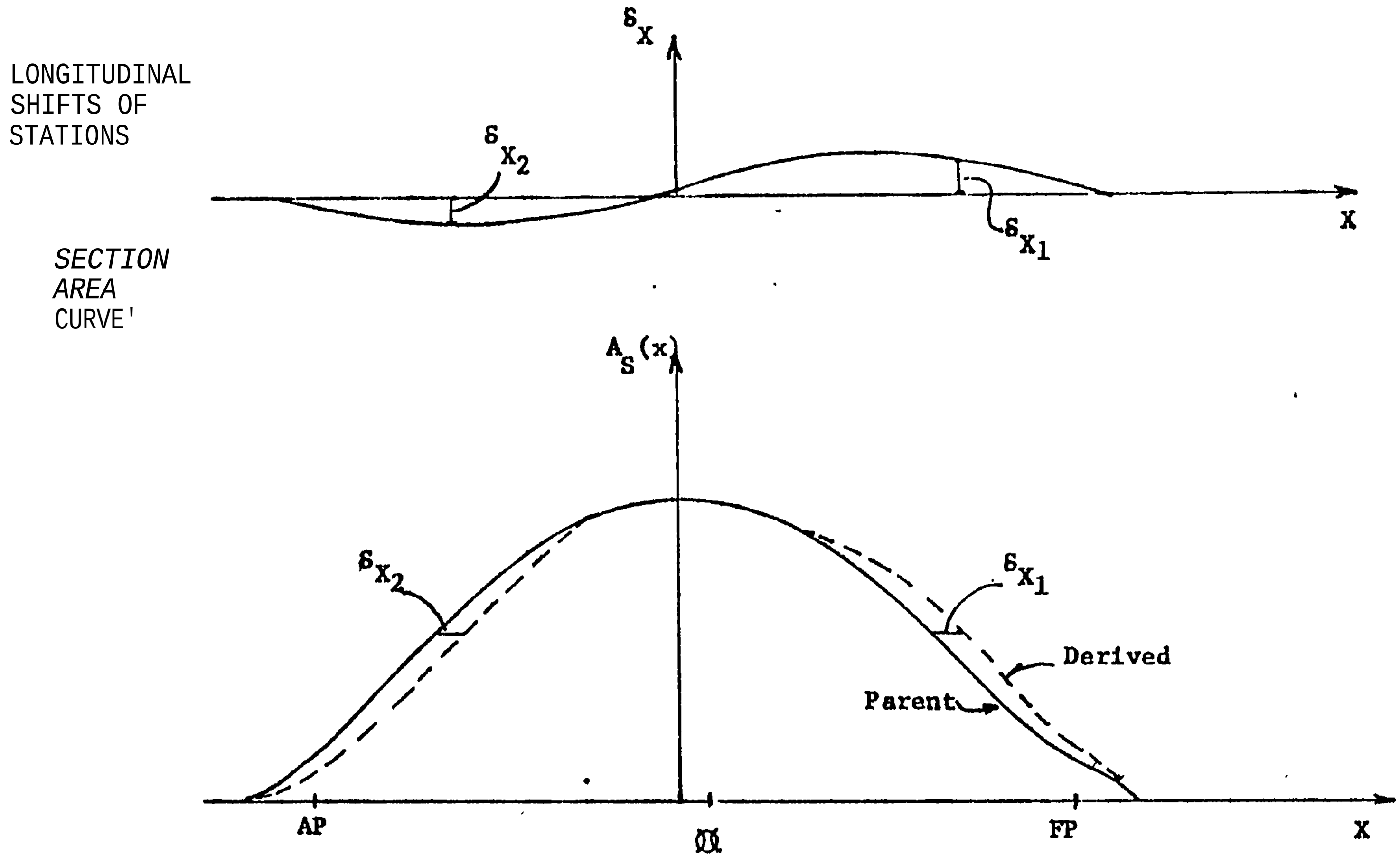

FIGURE 3. Longitudinal Shifts of Stations with Corresponding Derived Section Area Curve

equations allows the independent variation of three section area curve parameters: prismatic coefficient, longitudinal center of buoyancy, and extent of parallel midbody. In this case the equations of longitudinal shifts of stations are second order or parabolic. This is essentially the system of equations in [l] but with modifications to overcome the three mentioned limitations. The second system of 12 linear simultaneous equations allows the independent variation of prismatic coefficient, longitudinal center of buoyancy, extent of parallel midbody, and the slopes at the entrance and run. This is an extension of the system of 10 equations. Here the equations of longitudinal shifts of stations are third order or cubic.

4. EQUATIONS FOR PARABOLIC LONGITUDINAL SHIFTS

Four equations result from considering the forebody, four equations for the aft-body, and two equations for the combined forebody and aftbody; hence a system of ten linear simultaneous equations. The equations for the aftbody are identical in form to the four equations for the forebody, but the unknown coefficients are different and the X axis is reversed. The lengths of forebody and aftbody are not restricted to being equal.

4a. FOREBODY ONLY

In Figure 4 the solid curve abc represents the forebody of the parent section area curve. The x-axis units are length and the y-axis units are area. The dashed curve ab'c represents the forebody of the derived section area curve. At a position x the parent curve abc is shifted longitudinally by an amount 8x to produce curve ab'c.

Parent Forebody Curve (abc)

∇_F = underwater volume of forebody
x_F = abscissa of centroid of ∇_F
p_F = length of parallel midbody
L_F = length of forebody
A_M = maximum section area
x = abscissa of a point on abc
$A_s(x)$ = ordinate corresponding to x
θ_{PF} = slope of entrance of parent forebody

Derived Forebody Curve (ab'c)

$\delta\nabla_F$ = change in volume
$x_{\delta F}$ = abscissa of centroid of $\delta\nabla_F$
δp_F = change in parallel midbody
δx = longitudinal shift of station at x
θ_{DF} = slope of entrance of derived forebody

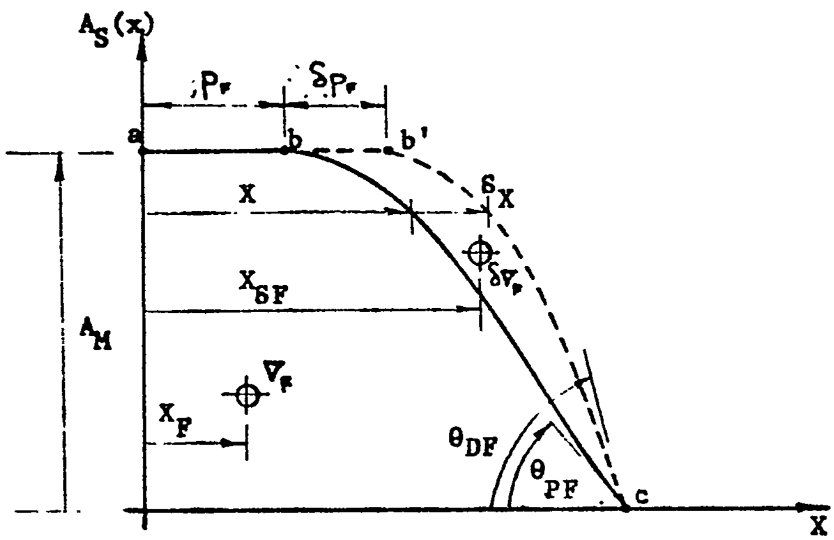

FIGURE 4. Forebody Section Area Curve

In order for the derived section area curve to have the desired prismatic coefficient, longitudinal center of buoyancy, and extent of parallel midbody, a second order expression of the following form is used for the longitudinal shifts in [1]:

(1) $8x = A(1-x)\ (x+B)$

where 8x is the necessary longitudinal shift at each position x along the fore-body and A and B are coefficients to be determined from the boundary conditions. Note that the term (l-x) includes the boundary condition that 8x be zero at the forward end of the curve i,e., at x=1 for a non-dimensionalized forebody length.

Instead of equation (1) we shall use a more general second order expression to simplify the algebra:

(2) $8\ x = Ax^2 + Bx + c$

where A, B, and C are constants to be determined from the boundary conditions.

Four equations for the forebody result from the following conditions:

(3) at $x = P_F$, $8x = 8_{pF}$ $\qquad 8X = 8_{pF} = A_{pF}{}^2 + B_{pF} + C$

(4) at $x = L_F$' $8x = 0$ $\qquad 8X = 0 = AL_F{}^2 + BL_F + C$

(5) $\delta\nabla_F = \int_0^{A_M} \delta x dA_S$ $\qquad \delta\nabla_F = 2A\nabla_F x_F + B\nabla_F + CA_M$

(6) $X_{\delta F}\delta\nabla_F = \int_0^{A_M} x\delta x dA_C$ $\qquad X_{\delta F}\delta\nabla_F = 3A\nabla_F K^2{}_F + 2B\nabla_F x_F + C\nabla_F$

where in equation (6) K_F is the radius of gyration about the A_S axis. There are **five unknowns: A, B, C, $\delta\nabla_F$, and $X_{\delta F}$.** All other quantities can be determined from the geometry of the forebody.

For the aftbody there are four more equations similar to (3), (4), (5), and (6) but with the coefficients A, B, C changed to D, E, F, respectively, and with subscript F replaced by A. In this case the five unknowns are D, E, F, $\delta\nabla_A$, and $X_{\delta A}$.

4b. COMBINED FOREBODY AND AFTBODY

The total section area curve will now be considered to develop the remaining two equations. Figure 5 shows the total section area curve with the various parameters labeled. The solid curve is the parent and the dashed curve is the derived.

Two equations for the total section area curve result from the following conditions:

$$(7) \qquad (\nabla + \delta\nabla)(X_{LCB} + \delta X_{LCB}) = \nabla X_{LCB} + \delta\nabla_F X_{\delta F} - \delta\nabla_A \times \delta A$$

The total change must equal the change forward plus the change aft.

$$(8) \qquad \delta\nabla = \delta\nabla_F + \delta\nabla_A$$

With equations (3), (4), (5), (6) for the forebody and four more equations similar to (3), (4), (5), (6) for the aftbody, and equations (7) and (8) for the total section area curve, we have a system of ten equations in ten unknowns. The equations are written in matrix form in Figure 6. The ten unknowns are contained in the column vector at the right. The matrix and the column vector at the left contain all known quantities. A direct numerical method like Gaussian elimination can be used for the solution. Once the coefficients A, B, C and D, E, F are calculated, the longitudinal shifts in the forebody are known

Parent Section Area Curve

∇ = underwater volume
= ∇ + v
x_{LCB} = longitudinal center of buoyance
P_F = length of parallel midbody in forebody
PA = length of parallel midbody In aftbody
θ_{PF} = slope of entrance of parent forebody
θ_{PA} = slope of run of parent aftbody

Derived Section Area Curve

$\delta\nabla$ = change in underwater volume
= $\delta\nabla + \delta\nabla$
$\delta\nabla_F$ = change in volume of forebody
$\delta\nabla_A$ = change in volume of aftbody
δx_{LCB} = change in longitudinal center of buoyancy
δp_F = change in parallel midbody in forebody
δp_A = change in parallel midbody in aftbody
θ_{DF} = **slope of entrance of derived forebody**
θ_{DA} = **slope of run of derived aftbody**

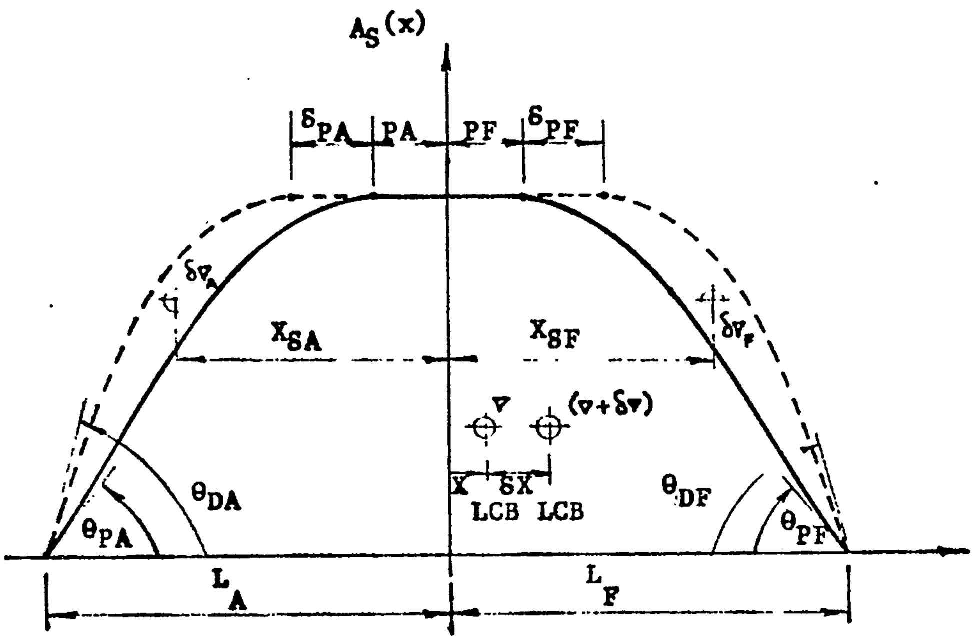

FIGURE 5. Total Section Area Curve

$$
\begin{Bmatrix}
\delta p_F \\ 0 \\ 0 \\ 0 \\ \delta p_A \\ 0 \\ 0 \\ 0 \\ \delta\nabla \\ (\nabla+\delta\nabla)(x_{LCB}+\delta x_{LCB})-\nabla x_{LCB}
\end{Bmatrix}
=
\begin{bmatrix}
p_F^2 & p_F & 1 & & & & & & & \\
L_F^2 & L_F & 1 & & & & & & & \\
2\nabla_F x_F & \nabla_F & A_M & -1 & & & & & & \\
3\nabla_F K_F^2 & 2\nabla_F x_F & \nabla_F & & -1 & & & & & \\
 & & & & & p_A^2 & p_A & 1 & & \\
 & & & & & L_A^2 & L_A & 1 & & \\
 & & & & & 2\nabla_A x_A & \nabla_A & A_M & -1 & \\
 & & & & & 3\nabla_A K_A^2 & 2\nabla_A x_A & \nabla_A & & -1 \\
 & & & 1 & & & & & 1 & \\
 & & & & 1 & & & & & -1
\end{bmatrix}
\begin{Bmatrix}
A \\ B \\ C \\ \delta\nabla_F \\ x_{\delta F}\,\delta\nabla_F \\ D \\ E \\ F \\ \delta\nabla_A \\ x_{\delta A}\,\delta\nabla_A
\end{Bmatrix}
$$

FIGURE 6. Ten Linear Simultaneous Equations for Parabolic Longitudinal Shifts

$$(9) \quad \delta X_F = Ax^2 + Bx + C$$

and the longitudinal shifts in the aftbody are known

$$(10) \quad \delta X_X + Dx^2 + Ex + F$$

When points on the parent section area curve are shifted longitudinally according to equations (9) and (10), the resulting section area curve will have the derived prismatic coefficient, longitudinal center of buoyancy, and extent of parallel midbody. When stations in the offsets are shifted longitudinally according to equations (9) and (10), a derived hull form will result which has these characteristics.

5. EQUATIONS FOR CUBIC LONGITUDINAL SHIFTS

In this case five equations result from considering the forebody, five equations from the aftbody, and two equations from the combined forebody and aftbody; hence a system of twelve linear simultaneous equations. Again the aftbody and fore-body equations are identical in form , but with different coefficients and different x-axis.

5a• FOREBODY ONLY

Figure 4 again applies, but the equation for longitudinal shifts becomes a third order expression.

$$(11) \quad \delta X = Ax^3 + Bx^2 + Cx + D$$

Where A, B, C, D, are constants to be determined from the boundary conditions.- The forth constant is required since there is an added boundary condition; the slope at the end of the curve is specified.

Five equations for the forebody result from the following conditions:

(12) at $x = L_F$, $\frac{dy}{dx}$ = specified value $\qquad \tan\theta_{PF}\cot\theta_{DF} - 1 = 3AL_F^2 + 2BL_F + C$

(13) at $x = P_F$, $\delta x = \delta p_F$ $\qquad \delta x = \delta p_F = Ap_F^3 + Bp_F^2 + Cp_F + D$

(14) at $x = L_F$, $\delta x = 0$ $\qquad \delta x = 0 = AL_F^3 + BL_F^2 + CL_F + D$

(15) $\delta\nabla_F = \int_0^{A_M} \delta x\, dA_S$ $\qquad \delta\nabla_F = 3A\nabla_F k_F^2 + 2B\nabla_F x_F + C\nabla_F + DA_M$

(16) $X_{\delta F}\,\delta\nabla_F = \int_0^{A_M} x\,\delta x\, dA_S$ $\qquad X_{\delta F}\delta\nabla_F = 4A\nabla_F R_F^3 + 3B\nabla_F K_F^2 + 2C\nabla_F X_F + D\nabla_F$

where in equation (12) $\tan\theta_{PF}$ is the slope of the parent curve at $X = L_F$ (which is known) and $\cot g_{DF}$ is the inverse of the slope of the derived curve at $X=L_F$ (which is specified) and where in equations (15) and (16) K_F is the radius of gyration (or lever of the second moment) about the A_S axis and in equation (16) R_F is the lever of the third moment about the A_S axis. There are six unknowns: A, B, D, D, $\delta\nabla_F$, $X_{\delta F}$. All other quantities can be determined from the geometry of the forebody.

For the aftbody there are five more equations similar to (12), (13), (14), (15), (16), but with coefficients A, B, C, D changed to E, F, G, H respectively and subscript F replaced by A. There the six unknowns are E, F, G, H, $\delta\nabla_A$, X_{SA}.

5b. Combined Forebody and Aftbody

Figure 5 applies and the two equations for the total section area curve are again equations (7) and (8). With equations (12), (13), (14), (15), (16) for the forebody, five similar equations for the aftbody, and equations (7) and (8) for

the total section area curve, we have a system of twelve equations in twelve unknowns. These equations are written in matrix form in Figure 7. The twelve unknowns are contained in the column vector at the right. The matrix and the column vector at the left contain all known quantities. Using Gaussian elimination for the solution the coefficients A, B, C, D and E, F, G, H are calculated and so the longitudinal shifts in the forebody are:

(17) $\delta x_F = Ax^3 + Bx^2 + Cx + D$

and the longitudinal shifts in the aftbody are

(18) $\delta x_A = Ex^3 + Fx^2 + Gx + H$

When points on the parent section area curve are shifted longitudinally according to equations (17) and (18), the resulting section area curve will have the desired prismatic coefficient, longitudinal center of buoyancy, extent of parallel midbody, slope of entrance, and slope of run. When stations in the offsets are shifted longitudinally according to equations (17) and (18), a derived hull fon will result which has these characteristics. A new hull will have been generated from a parent hull using section area curve variation.

$$
\left\{\begin{matrix}
\tan\theta_{PF}\cot\theta_{DF} - 1 \\
\delta p_F \\
0 \\
0 \\
0 \\
\tan\theta_{PA}\cot\theta_{DA} - 1 \\
\delta p_A \\
0 \\
0 \\
0 \\
\delta\nabla \\
(\nabla+\delta\nabla)(x_{LCB}+\delta x_{LCB}) - \nabla x_{LCB}
\end{matrix}\right\}
=
\begin{bmatrix}
3L_F^2 & 2L_F & 1 & & & & & & & & & \\
p_F^3 & p_F^2 & p_F & 1 & & & & & & & & \\
L_F^3 & L_F^2 & L_F & 1 & & & & & & & & \\
3\nabla_F K_F^2 & 2\nabla_F X_F & \nabla_F & & -1 & & & & & & & \\
4\nabla_F R_F^3 & 3\nabla_F K_F^2 & 2\nabla_F X_F & \nabla_F & & -1 & & & & & & \\
 & & & & & & 3L_A^2 & 2L_A & 1 & & & \\
 & & & & & & p_A^3 & p_A^2 & p_A & 1 & & \\
 & & & & & & L_A^3 & L_A^2 & L_A & 1 & & \\
 & & & & & & 3\nabla_A K_A^2 & 2\nabla_A X_A & \nabla_A & & -1 & \\
 & & & & & & 4\nabla_A R_A^3 & 3\nabla_A K_A^2 & 2\nabla_A X_A & \nabla_A & & -1 \\
 & & & & 1 & & & & & & 1 & \\
 & & & & & 1 & & & & & & -1
\end{bmatrix}
\left\{\begin{matrix}
A \\
B \\
C \\
D \\
\delta\nabla_F \\
x_{SF}\delta\nabla_F \\
E \\
F \\
G \\
H \\
\delta\nabla_A \\
x_{SA}\delta\nabla_A
\end{matrix}\right\}
$$

FIGURE 7. Twelve Linear Simultaneous Equations for Cubic Longitudinal Shifts

6. CONCLUSIONS

Some typical computer methods for generating new ship lines were first briefly discussed. Then the lines distortion approach of section area curve variation was presented in detail. A systematic mathematical approach to section area curve variation using matrices was developed which gives a closed form solution and simplifies changing the boundary conditions. The derivation of a system of twelve linear simultaneous equations for cubic longitudinal shifts demonstrates how two more boundary conditions are easily added to the original system of ten equations. Several examples with numeric and graphic results from a computer program developed at the Maritime Administration are presented. The graphic results demonstrate that the derived section area curves look reasonable and the numeric results show that the derived curve has the desired form parameters.

Development is underway to add calculations and plots of the non-dimensional curvature of both parent and derived section area curves to the computer program. This would show how section area curve variation affects the curvatures on the parent section area curve. Additionally, it would be interesting to see the results of using section area curve variation on a hull which was faired by a program like HULDEF, since the program has not been tested on a construction design. In any case the method presented should be adequate for generating new lines for preliminary design, with the restriction that changes be moderate, i.e., up to 10% change in prismatic coefficient and about 2% change in longitudinal center of buoyancy.

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8. NUMERIC AND GRAPHIC RESULTS

a. Example 1 - parabolic longitudinal shifts
shift LCB forward, increase Cp

b. Example 2 - parabolic longitudinal shifts
shift LCB forward, increase Cp, add parallel midbody

c. Example 3 - parabolic longitudinal shifts
shift LCB aft, decrease Cp, set forebody/aftbody boundary

d. Example 4 - cubic longitudinal shifts
shift LCB aft, decrease Cp, set forebody/aftbody boundary

EXAMPLE 1

PARENT. NO PARALLEL MIDBODY, NO BULB
DERIVED. SHIFT LOB FORWARD INCREASE CP .

VALUE OF DETERMINANT
0.42210771E+23

	PARENT X	DELTA X	DERIVED X	AREA
1	0.0000	0.0000	0.0000	253.5500
2	14.0000	-3.5108	10.4892	301.5690
3	28.0000	-6.6800	21.3200	341.0370
4	42.0000	-9.5076	32.4924	405.4760
5	56.0000	-11.9937	44.0063	555.8600
6	84.0000	-15.9411	68.0589	947.1400
7	112.0000	-18.5221	93.4779	1387.9659
8	140.0000	-10.7368	120.2632	1819.8840
9	168.0000	-10.5852	148.4148	2194.8540
10	196,0000	-18. .0672	177.9328	2479.9971
11	224.0000	-15.1829	208.8171	2671.6680
12	252.0000	-10.9323	241.0677	2778.4651
13	280.0000	-5.3154	274.6846	2804.5161
14	301.7856	0.0000	301.7856	2811.3486
15	304.0000	0.3934	304.3934	2811.2581
16	336.0000	5.3191	341.3191	2756.2529
17	364.0000	8.4630	372.4630	2626.2661
18	392.0000	10.5188	402.5188	2418.4031
19	420.0000	11.4862	431.41362	2118.8689
20	448.0000	11.3655	459.3655	1728.0400
21	476.0000	10.1565	48.1565	1236.4340
22	504.0000	7.8592	511.8592	724.7050
23	532.0000	4.4737	536.4738	248.6890
24	560.0000	0.0000	560.0000	15.2270

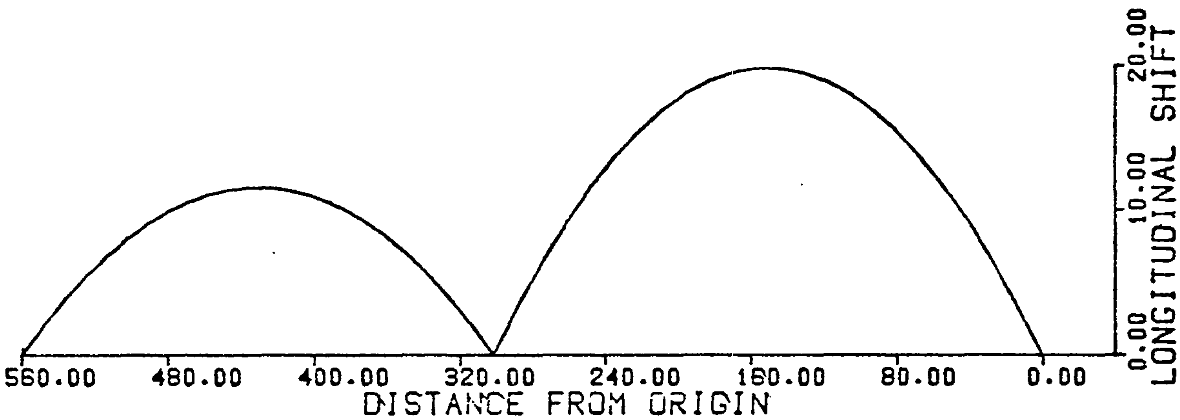
	DERIVED X	DELTA X	PARENT X	AREA
1	0.0000	0.0000	0.0000	253.5500
2	14.0000	4.7316	18.7316	315.2173
3	28.0000	8.5118	36.5118	372.8656
4	42.0000	11.5703	53.5703	524.5657
5	56.0000	14.1343	70.1343	747.3918
6	84.0000	17.5774	101.5774	1224.1975
7	112.0000	19.5896	131.5896	1690.9563
8	140.0000	20.0106	160.0106	2093.2683
9	168.0000	19.1748	187.1748	2396.9578
10	196.0000	17.3467	213.3467	2604.1907
11	224.0000	14.8907	238.8907	2735.2859

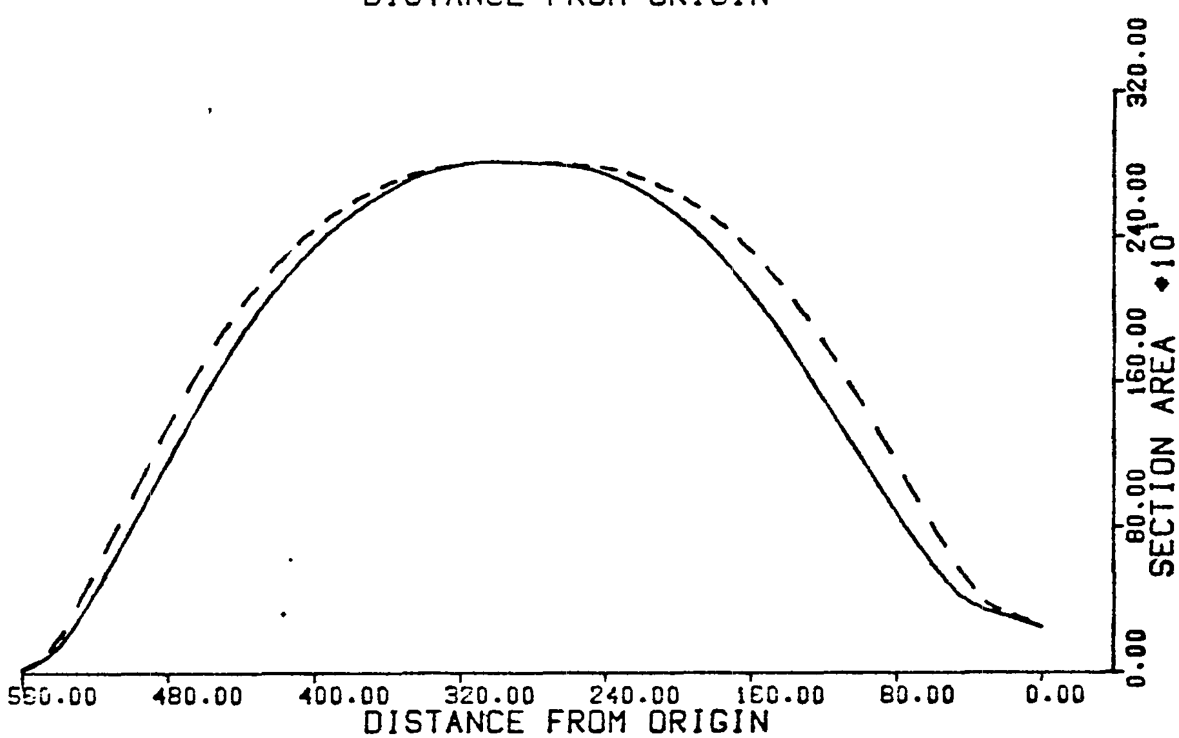
12	252.0000	7.9638	259.9638	2789.9961
13	280.0000	3.3310	283.3310	2806.1023
14	301.7856	0.0000	301.7856	2811.3486
15	304.0000	-1.2838	302.7162	2811.3223
16	336.0000	-3.7207	332.2793	2768.6643
17	364.0000	-7.9975	356.0025	2669.9341
18	392.0000	-10.0361	381.9639	2501.3291
19	420.0000	-11.2910	408.7040	2349.8271
20	448.0000	-11.7303	436.2697	1905.1338
21	476.0000	-10.9098	465.0902	1431.2815
22	504.0000	-8.5561	495.4439	881.1740
23	532.0000	-5.2440	526.7560	333,2687
24	560.0000	0.0000	560.0000	15.3270

DEPIVED SECTION AREA CURVE-DFSIRED VALUES	(PROGRAM INPUT)
PRISNATIC COFFFICIENT	0.6610
LOB (ABOUT ORIGIN)	283.0000
CHANGE IN PARALLEL MIDBODY IN FOREBODY	0.0000
CHANGE IN PARALLEL MIDBODY IN AFTBODY	0.0000

PARENT SECTION AREA CURVE-ACTUAL VALUES	(PROGRAM OUTPUT)	
	TOTAL	
PRISMATIC COEFFICIENT	0.6189	
LOB (ABOUT ORIGIN)	285.2349	
MAXIMUM SECTION AREA	2911.3486	
X VALUE. WHERE SECTION AREA IS MAX	301.7856	
	FOREBODY	AFTRODY
PRISMATIC COEFFICIENT	0.6236	0.6133
X VALUE WHERE SA CURVE HAS ZERO SLOPE	301.7856	301.7856
LENGH OF PARALLEL MIDBODY	0.0000	0.0000
LOG (ABOUT X AT MAX SA)	105.6420	89.3171
RADIUS OF GYRATION (ABOUT X AT MAX SA)	126.9857	106.8458

DERIVED SECTION AREA CURVE-ACTUAL VALUES	(PROGRAM OUTPUT)	
	FOREBODY	AFTBODY
CHANGE IN PRISMATIC COEFFICIENT	0.0492	0.0339
LOG OF CHANGE IN CP (ABOUT X AT MAX SA)	170.0123	149.2565
	TOTAL (ON UNEVEN SPACING)	
PRISMATIC COEFFICIENT	.0.6610	
PEPCENT CP ERROR (ACTUAL VS DESIRED)	0.0013	
LOB (ABOUT ORIGIN)	282.7675	
PERCENT LOB ERROR (ACTUAL VS DESIRED)	-0.0822	
	TOTAL (ON EVEN SPACING)	
PRISMATIC COEFFICIENT	0.6612	
PERCENT CP ERROR (ACTUAL VS DESIRED)	0.0324	
LOP (ABOUT ORIGIN)	282.8586	
PERCENT LOB ERROR (ACTUAL VS DESIRED)	-0.0500	





PARENT. NO PARALLEL MIDBODY.NO BULB
DERIVED. SHIFT LCB FORWARD.INCREASE CP

EXAMPLE 2

PARENT. N0 PARALLEL MIDBODY, AXIS AT FP
DERIVED. SHIFT LCB FWD, INCREASE CP, ADD PARALLEL MIDBODY

VALUE OF DF DETERMINANT
0.19152752E+22

	PAPENT X	DELTA X	DERIVED X	AREA
1	0.0000	0.0000	0.0000	0.0000
2	5.0000	-0.4833	4.5167	15.7600
3	10.0900	-0.9628.	9.0372	55.9200
4	15.0000	-1.4386	13.5614	104.7000
5	20.0000	-1.9106	18.0894	155.8200
6	30.0000	-2.8434	27.1566	260.0600
7	40.0000	-3.7611	36.2389	370.3000
8	50.0000	-4.6639	45.3361	489.2900
9	60.0000	-5.5517	54.4493	615.3700
10	80.0000	-7.2823	72.7177	877.4300
11	100.0000	-8.9529	91.0471	1135.4000
12	120.0000	-10.5635	109.4365	136R.1100
13	160.0000	-13.6047	146.3953	1685.9200
14	200.0000	-16.4059	183.5941	1764.9100
15	206.6624	-16.8624	190.0000	1766.2482
16	206.8624	3.1376	210.0000	1766.2482
17	240.0000	2.2524	242.2534	1728.4100
18	280.0000	1.3765	281.3765	1497.5699
19	300.0000	1.0175	301.0175	1257.3700
20	320.0000	0.7113	320.7113	959.1800
21	339.0000	0.5779	330.5779	796.7300
22	340.0000	0.4577	340.4577	630.0800
23	350.0000	0.3507	350.3506	464.8100
24	360.0000	0.2568	360.2568	309.1600
25	370.0000	0.1761	370.1761	168.3500
26	375.0000	0.1407	375.1407	104.7400
27	380.0000	0.1086	380.1086	44.4800
28	390.0000	0.0542	390.0542	3.7900
29	395.0000	0.0320	395.0320	1.0600
30	400.0000	0.0130	400.0131	0.2100
31	404.0900	0.0000	404.0900	0.0400

DEPINED SECTION AREA CURVE-DESIRED VALUES (PROGRAM INPUT

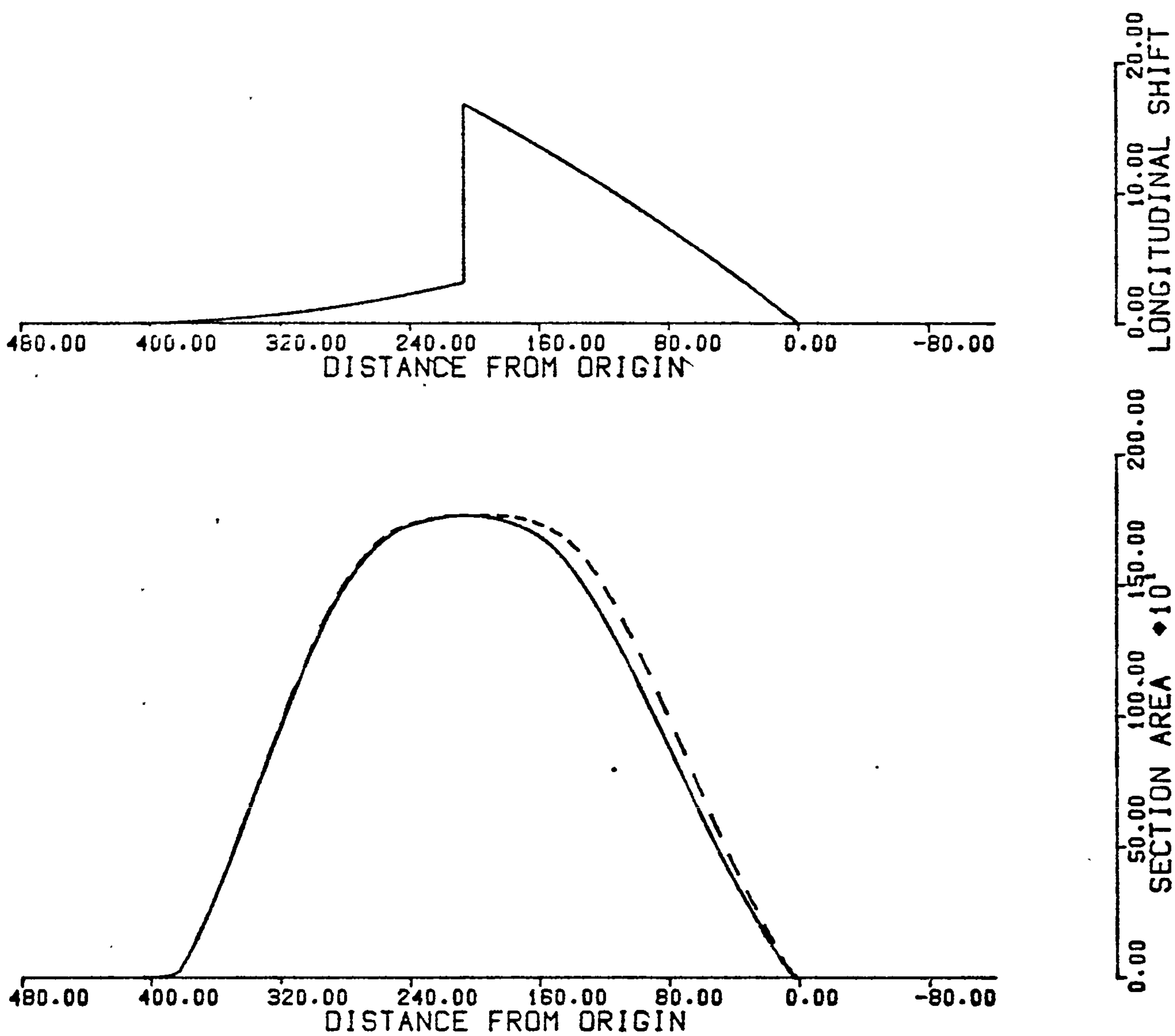
PRISMATIC COEFFICIENT	0.6120
LCB (ABOUT ORIGIN)	198.0600
CHANGE IN PARALLEL MIDBODY IN FOREBODY	16.8624
CHANGE TN PARALLEL MIDBODY TN AFTBODY	3.1376

PARENT SECTION AREA CURVE-ACTUAL VALUES (PROGRAM OUTPUT)

	-TOTAL	
PRISMATIC COEFFICIENT	0.5919	
LCB (ABOUT ORIGIN)	200.5799	
MAXIMUM SECTION AREA	1766.2482	
X VALUE WHERE SECTION APEA IS MAX	206.8624	
	FORE BODY	AFIBODY
PRISMATIC COEFFICIENT	0.6024	0.5810
X VALUE WHERE SA CURVE HAS ZERO SLOPE	206.8624	206.8624
LENGTH OF PARALLEL MIDBODY	0.0000	0.0000
LCG (ABOUT X AT MAX SA)	70.3265	63.3594
RADIUS OF GYRATION (ABOUT X AT MAX SA)	84.5154	75.8073

DERIVED SECTION AREA CURVE-ACTUAL VALUES (PROGRAM OUTPUT)

	FOREBODY	AFTBODY
CHANGE IN PRISMATIC COEFFICIENT	0.0354	0.0040
LCG OF CHANGE IN CP (ABOUT X AT MAX SA)	101.6077	85.4954
	TOTAL (ON UNEVEN SPACING)	
PRISMATIC COEFFICIENT	0.6120	
PERCENT CP ERROR (ACTUAL VS DESIRED)	0.0011	
LCB (ABOUT ORIGIN)	197.8740	
PERCENT LCB ERROR (ACTUAL VS DESIRED1	-0.0940	
	TOTAL (ON EVEN SPACING)	
PRISMATIC COEFFICIENT	0.6117	
PERCENT CP ERROR (ACTUAL VS DESIRED)	-0.0443	
LCB (ABOUT ORIGIN)	197.6116	
PERCENT LCB ERROR (ACTUAL VS DESIRED)	-0.2269	



PARENT. NO PARALLEL MIDBODY,Y AXIS AT FP
DERIVED. SHIFT LCB FWD,INCREASE CP,ADD PARALLEL MIDBODY

EXAMPLE 3

PARENT. WITH PARALLEL MIDBODY
DERIVED. SHIFT LCB AFT, DECREASE CP, SET F/A BOUNDARY

VALUE OF DETERMINANT
0.17685459E+04

	PARENT X	DELTA X	DERIVED X	AREA
1	0.0000	0.0000	0.0000	0.0000
2	0.2500	0.0391	0.2891	0.0510
3	0.5000	0.0729	0.5729	0.1410
4	0.7500	0.1016	0.8516	0.2580
5	1.0000	0.1251	1.1351	0.3810
6	1.5000	0.1563	1.6563	0.6230
7	2.0060	0.1667	2.1667	0.8190
8	2.5000	0.1563	2.6563	0.9440
9	3.0000	0.1251	3.1251	0.9880
10	4.0000	-0.0000	4.0000	1.0000
11	4.2000	0.0000	4.2000	1.0000
12	5.0000	0.0000	5.0000	1.0000
13	6.0000	-0.0261	5.9739	0.9990
14	7.0000	-0.0391	6.9609	0.9210
15	7.5000	-0.0407	7.4593	0.8260
16	8.0000	-0.0301	7.9609	0.6880
17	8.5000	-0.0342	8.4658	0.5100
18	9.0000	-0.0261	8.9739	0.3280
19	9.2500	-0.0208	9.2292	0.2360
20	9.5000	-0.0147	9.4853	0.1510
21	9.7500	-0.0077	9.7423	0.0690
22	10.0000	0.0000	10.0000	0.0150

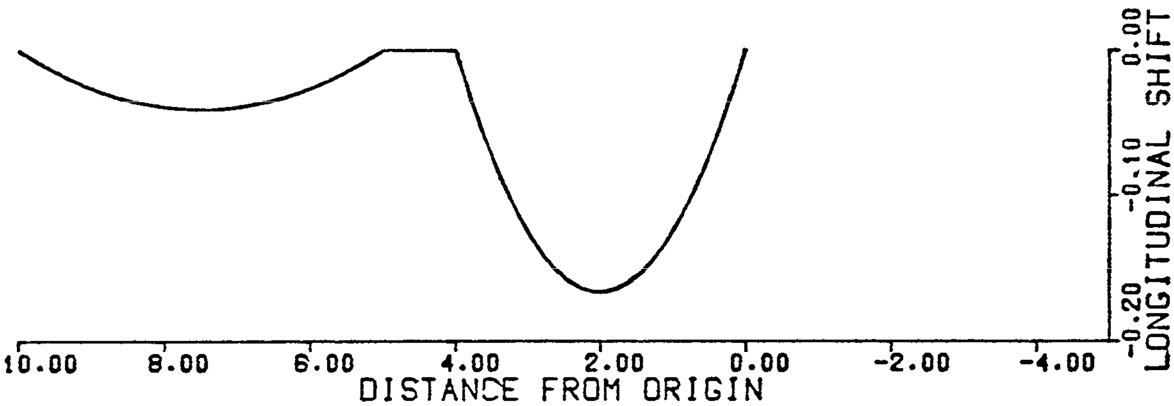
	DERIVED X	DELTA X	PARENT X	AREA
1	0.0000	0.0000	0.0000	0.0000
2	0.2500	-0.0351	0.2149	0.0414
3	0.5000	-0.0651	0.4349	0.1136
4	0.7500	-0.0925	0.6575	0.2137
5	1.0000	-0.1146	0.8854	0.3246
6	1.5000	-0.1477	1.3523	0.5519
7	2.0000	-0.1577	1.8423	0.7605
8	2.5000	-0.1285	2.3715	0.9143
9	3.0000	-0.0909	2.9091	0.9827
10	4.0000	0.0000	4.0000	1.0000

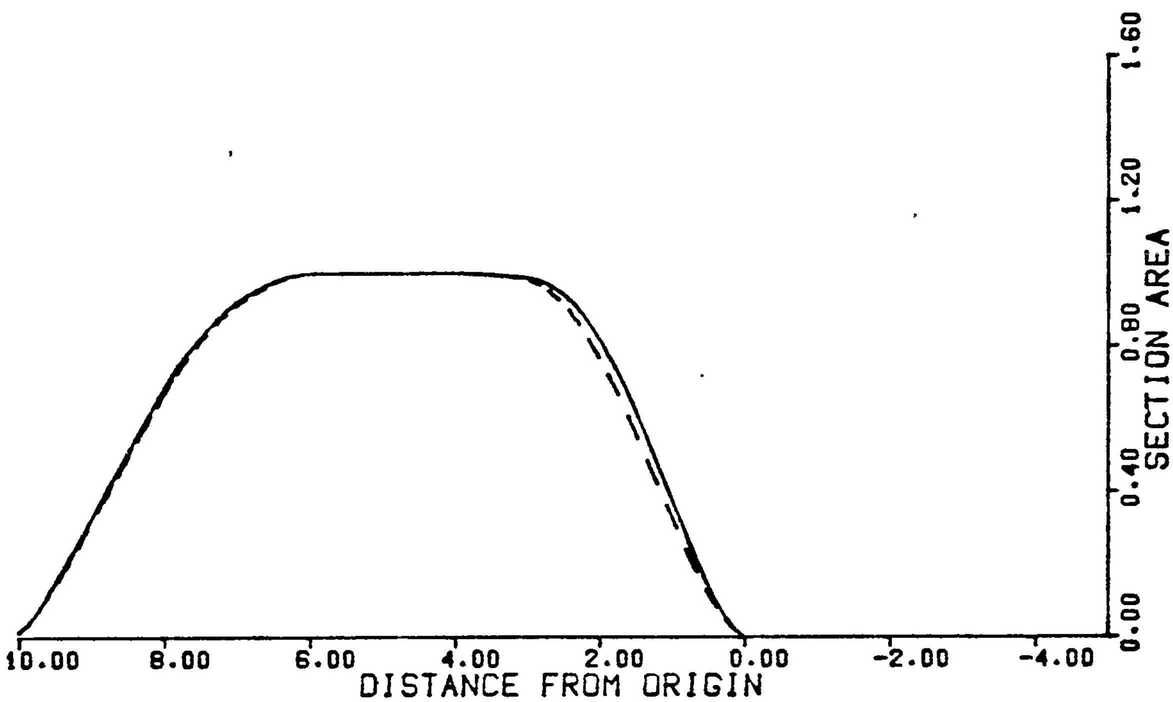
11	4.2000	0.0000	4.2000	1.0000
12	5.0000	0.0000	5.0001)	1.0000
13	6.0000	0.0023	6.0023	9.9989
14	7.0000	0.0288	7.0288	0.9156
15	7.5000	0.0373	7.5373	0.8162
16	8.0000	0.0386	8.0386	0.6744
17	8.5000	0.0337	8.5337	0.4978
18	9.0000	0.0256	9.0256	0.3186
19	9.2500	0.0205	9.2705	0.2287
20	9.5000	0.0143	9.5143	0.1462
21	9.7500	0.0076	9.7576	0.0667
22	10.0000	0.0000	10.0000	0.0150

DERIVED SECTION AREA CURVE-DESIRED VALUES	(PROGRAM INPUT)
PRISMATIC COEFFICIENT	0.7000
LCB (ABOUT ORIGIN)	4.9500
CHANGE IN PARALLEL MIDBODY TN FOREBODY	0.0000
CHANGE IN PARALLEL MIDBODY IN AFTBODY	0.0000

PARENT SECTION AREA CURVE-ACTUAL VALUES	(PROGRAM OUTPUT)	
	TOTAL	
PRISMATIC COEFFICIENT	0.7154	
LCB (ABOUT ORIGIN)	4.9027	
MAXIMUM SECTION AREA	1.0000	
X VALUE WHERE SECTION AREA IS MAX	4.2000	
	FOREBODY	AFTBODY
PRISMATIC COEFFICIENT	0.6902	0.7337
X VALUE WHERE SA CURVE HAS ZERO SLOPE	4.0000	5.0000
LENGTH OF PARALLEL MIDBODY	0.2000	9.8000
LCG (ABOUT X AT MAX SA)	1.5381	2.2292
RADIUS OF GYBATION (ABOUT X AT MAX SA)	1.8176	2.6257

DERIVED SECTION AREA CURVE-ACTUAL VALUES	(PROGRAM OUTPUT)	
	FOREBODY	AFTBODY
CHANGE TN PRISMATIC COEFFICIENT	-0.0298	-0.0050)
LCG OF CHANGE IN CP (ABOUT X AT MAX SA)	2.6916	3.9028
	TOTAL (ON UNEVEN SPACING)	
PRISMATIC COEFFICIENT	0.7000	
PERCENT CP ERROR (ACTUAL VS DESIRED)	0.0024	
LCB (ABOUT ORIGIN)	4.9492	
PERCENT LCB ERROR (ACTUAL VS DESIRED)	-0.0155	
	TOTAL (0N EVEN SPACING)	
PRISMATIC COEFFICIENT	0.7000	
PERCENT CP ERROR (ACTUAL VS DESIRED)	0.0046	
LCB (ABOUT ORIGIN)	4.9495	
PERCENT LCB ERROR (ACTUAL VS DESIRED)	-0.0110	





PARENT. WITH PARALLEL MIDBODY
DERIVED. SHIFT LCB AFT.DECREASE CP.SET F/A BOUNDARY

EXAMPLE 4

PARENT. WITH PARALLEL MIDBODY
DERIVED. SHIFT LCB AFT, DECREASE CP, SET F/A BOUNDARY

I

VALUE OF DETERMINANT
0.17685459E+04

	PARENT X	DELTA X	DERIVED X	AREA
1	0.0000	0.0000	0.0000	0.0000
2	0.2500	0.0391	0.2891	0.0510
3	0.5000	0.0729	0.5729	0.1410
4	0.7500	0.1016	0.8516	0.2580
5	1.0000	0.1251	1.1251	0.3810
6	1.5000	0.1563	1.6563	0.6230
7	2.0000	0.1667	2.1667	0.8190
8	2.5000	0.1563	2.6563	0.9440
9	3.0000	0.1251	3.1251	0.9880
10	4.01300	-0.0000	4.0000	1.0000
11	4.2000	0.0000	4.2000	1.0000
12	5.0000	0.0000	5.0000	1.0000
13	6.0000	-0.0261	5.9739	0.9890
14	7.0000	-0.0391	6.9609	0.9210
15	7.5000	-0.0407	7.4593	0.8260
16	8.0000	-0.0391	7.9609	0.6880
I7	8.5000	-0.0342	8.4658	0.5100
18	9.0000	-0.0261	8.9739	0.3289
19	9.2500	-0.0208	9.2292	0.2360
20	9.5000	-0.0147	9.4853	0.1510
21	9.7500	-0.0077	9.7423	0.0690
22	10.0000	0.0000	10.0000	0.0150

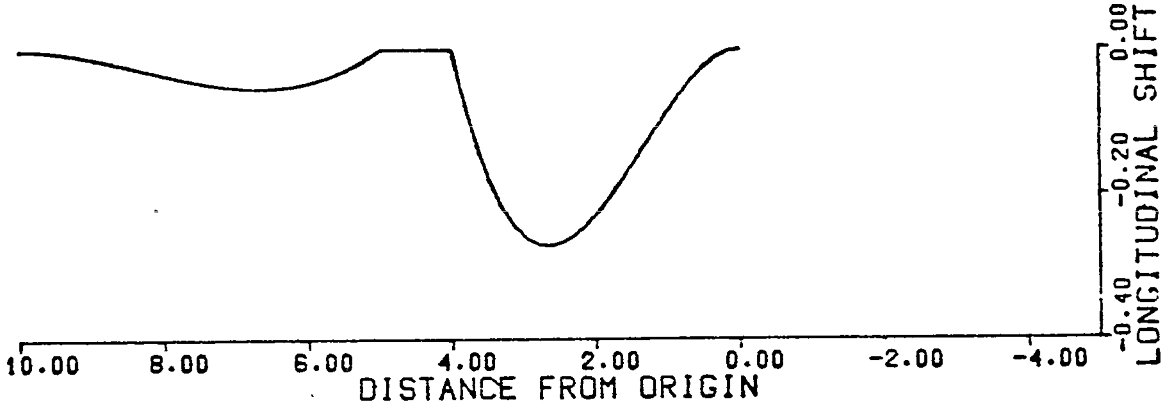
	DERIVED X	DELTA X	PARENT X .	AREA
1	0.0000	0.0000	0.0000	0.0000
2	0.2500	-.0351	0.2149	0.0414
3	0.5000	-0.0651	0.4349	0.1136
4	0.7500	-0.0925	0.6575	0.2137
5	1.0000	-0.1146	O.8854	0.3246
6	1.5000	-0.1477	1.3523	0.5519
7	2.0000	-0.1577	1.8423	0.7605
8	2.5000	-0.1285	2.3715	0.9143
9	3.0000	-0.0909	2.9091	0.9827
10	4.0000	0.0000	4.0000	1.0000
11	4.2000	0.0000	4.2000	l.0000

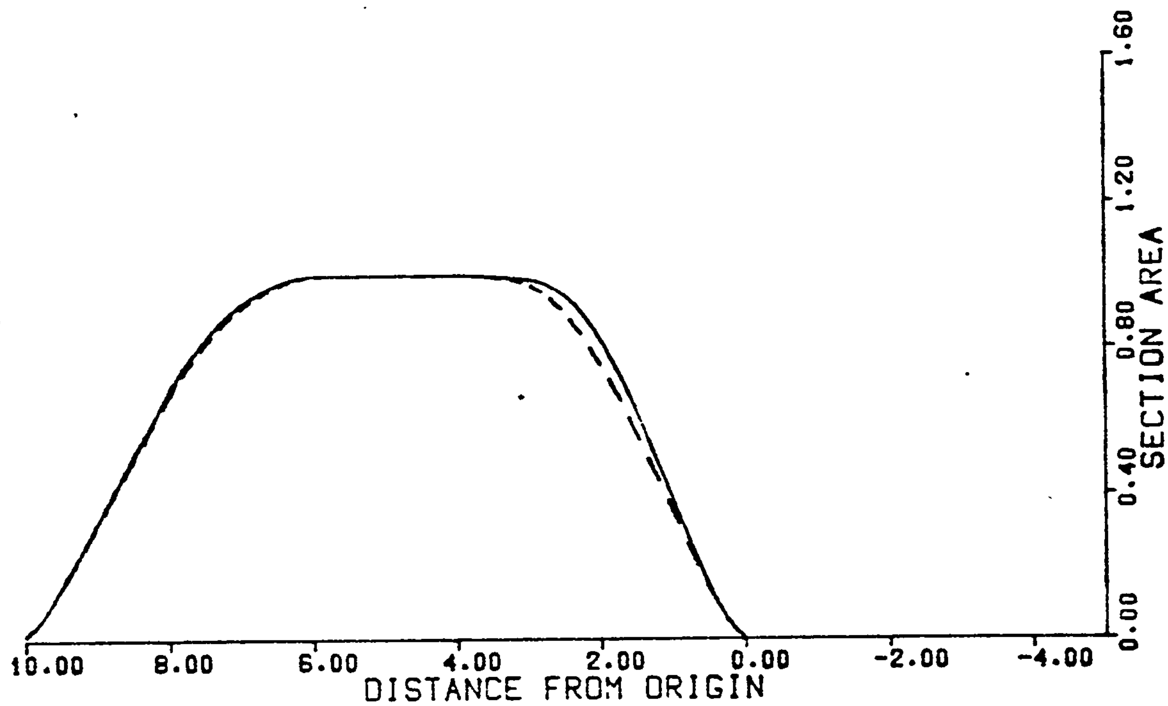
12	5.0000	0.00000	5.0000	1.0000
13	6.0000	0.0023	6.0023	0.9989
14	7.0000	0.0288	7.0288	0.9156
15	7.5000	0.0373	7.5373	0.8162
16	8.0000	0.0386	8.0386	0.6744
17	8.5000	0.0337	8.5337	0.4978
18	9.0000	0.0256	9.0256	0.3186
19	9.2500	0.0205	9.2705	0.2287
20	9.5000	0.0143	9.5143	0.1462
21	9.7500	0.0076	9.7576	0.0667
22	10.0000	0.0000	10.0000	0.0150

DERIVED SECTION AREA CURVE-DESIRED VALUES	(PROGRAM INPUT)
PRISMATIC COEFFICIENT	0.7000
LCB (ABOUT ORIGIN)	4.0500
CHANGE IN PARALLEL MIDBODY IN FOREBODY	0.0000
CHANGE IN PARALLEL MIDBODY IN AFTBODY	0.0000

PARENT SECTION AREA CURVE-ACTUAL VALUES	(PROGRAM OUTPUT)	
	TOTAL	
PRISMATIC COEFFICIENT	0.7154	
LCB (ABOUT ORIGIN)	4.9027	
MAXIMUM SECTION AREA	1.0000	
X VALUE WHERE SECTION AREA IS MAX	4.20000	
	FOREBODY	AFTBODY
PRISMATIC COEFFICIENT	0.6902	0.7337
X VALUE WHERE SA CURVE HAS ZERO SLOPE	4.0000	5.0000
LENGTH OF PARALLEL MIDBODY	0.2000	0.8000
LCG (ABOUT X AT MAX SA)	1.5381	2.2292
RADIUS OF GYRATION (ABOUT X AT MAX SA)	1.8176	2.6257

DERIVED SECTION AREA CURVE-ACTUAL VALUES	(PROGRAM OUTPUT)	
	FOREBODY	AFTBODY
CHANGE IN PRISMATIC COEFFICIENT	-0.0298	-0.0050
LCG OF CHANGE IN CP (ABOUT X AT MAX SA)	2.6916	3.9028
	TOTAL CON UNEVEN SPACING)	
PRISMATIC COEFFICIENT	0.7000	
PERCENT CP ERROR (ACTUAL VS DESIRED)	0.0024	
LCB (ABOUT ORIGIN)	4.9492	
PERCENT LCB ERROR (ACTUAL VS DESIRED)	-0.0155	
	TOTAL (ON EVEN SPACING)	
PRISMATIC COEFFICIENT	0.7000	
PERCENT CP ERROR (ACTUAL VS DESIRED)	0.0046	
LCB (ABOUT ORIGIN)	4.9495	
PERCENT LCB ERROR [ACTUAL VS DESIRED)	-0.0110	





PARENT. WITH PARALLEL MIDBODY
DERIVED. SHIFT LCB AFT.DECREASE CP.SET F/A BOUNDARY

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